GRBs and the Ghost of the Fireball

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ABSTRACT. Gamma Ray Burst has been widely believed in last decade to be super-explosions: the Fireball. We are argue on the contrary that GRBs (as well as Soft Gamma Repeaters SGR) are precessing Gamma Jets. We remind the list of contradiction that Fireball and its galactic smaller version, the magnetar,have to face. In particular the existence of weak isolated X-ray precursor signal before the main Gamma Ray Burst and (rare SGR) events disagree with any explosive, one shoot, scenarios either isotropic or wide-beamed. We interpret them as earlier marginal blazing of outlying X conical Jet tails of precessing, spinning γ Jet.

1. Introduction: GRBs and the blow up of the energy

Gamma Ray Burst, GRB, has been associated in last decade with huge explosions many order of magnitude (10^{10}) more power-full than common Supernova. These bursts are so intense (because of GRB cosmic distance origin) and energetic (at the electron mass edges) as well as so sharp (within millisecond scale in time) that their own opacity (at corresponding small hundred kilometers sizes) make difficult their own shining outside (an over Eddington luminosity). This Eddington-opacity is reached also for smaller distance (and less power-full) sources, named Soft Gamma Repeaters SGRs, because softer and sometime repeating. For all last decade ruled Fireball: a huge isotropic explosive model where boosted relativistic electron pairs sea and their annihilation may have remitted soft KeV photons into harder MeV energy band in a wide shells. The GRBs structure arises in Fireball by internal-external shell scattering. We considered since 1993 the γ Jet model for GRBs and SGRs both of them at largest galactic halo; after the rare GRB 980425 and its Supernova-GRB connection, we committed to explain both of them as a precessing Jet at different energy regime, both for GRBs at Supernova beamed power and SGRs at much lower X-pulsar beamed luminosity. Most of the scientific community remained firmly on Fireball model before and after the first cosmic identification of GRB at cosmic edges on February 1997. For me in that epoch was difficult to accept huge supernova jet and I preferred a galactic halo model; since April 25 GRB, however, I immediately believed in GRB and SGR unified model at huge different beamed powers. However the fireball believers, a formidable school all over the world, increased their excitement as much as the GRB distance (or redshift) and its apparent output power was increased by event to event. Their explosive model was feed by the apparent X-decay after-glow tail. Nevertheless the huge $GRB990123$ event blow up too much even for the most excited mind: its unbelievable energy puzzle (imagine, two or more solar masses totally converted in pure gamma within tens of seconds within

a millisecond-hundred kilometer substructures) forced most authors to bend their collimate Fireball model toward en-longed beamed Jet, in order to economize the energy. Therefore with a polite compromise the Fireball models shifted toward a wide (ten degrees or so) open cone or a Fountain Jet Models. Still one-shoot Fireball model. How was possible to hold slimy neutrino in such a Jet is a mystery. No general agreement on the Supernova-GRB connection was in general acceptable to Fireball believers. The new Jet-Fireball shared still the explosive nature and the shock wave time modulation ruled by external relic shells, but it relaxed the energy demand by the inverse of the solid angle beam. The word beam or jet has been often hidden under new fashionable names. As the time went on the beam of Fireball's model shrinks and the GRBs energy reduces from ($\gg 10^{54}\ erg$) first to ($\gg 10^{51}\ erg$) and even toward ($\gg 10^{48}\ erg$). However the smaller the (explosive) beam angle the higher is the needed GRB event rate: from nominal 10^{-6} event a year for galaxy one must expect a more frequent 10^{-3} or even 1 GRB a year in galaxies. Therefore we must accept the co-existence in our Universe of two totally separate wild animals: Supernova whose explosive isotropic output reaches $10^{44}\ erg\ s^{-1}$ powers and a total energy $10^{51}\ erg$ and a as common as animal whose jet output is $10^{48}\ erg\ s^{-1}$ and total energy $10^{51}\ erg$. A possible GRB-Supernova connection call for an additional paradox: Why GRB Fireball-Jet power is 4-7 order of magnitude higher than the corresponding optical one in Supernova. Why not to respect at least energy equi-partition? In this Fireball scenario the rare GRB of April 1998 stand outside or better is often hidden or taken away because of the more puzzling apparent *low* energy output and softer nature while being nearer and un-red-shifted. Of course off-axis Fireball event make the miracle but cannot solve the statistics.
We argued (1998-1999) on the contrary that GRBs and SGRs find a comprehensive theory within a very thin (tens of seconds) spinning and multi precessing γ Jet, sprayed by a Neutron Star, NS, or Black Hole, BH, (Fargion 1994-1999, Fargion, Salis 1995-1998). Higher black holes mass (10^1 10^4 solar masses) cannot help Fireball isotropic survival because contradictions with the sharp GRB time-scales. We have shown that the same rarity of GRB-SN detection and the established GRB980425-SN link favors very clearly the thin (tens of arc second or millisecond radiant) Jet Nature of GRBs. Such thin jet may accommodate the Supernova power into an apparent GRB luminosity in agreement with energy equi-partition. Moreover the Jet in precession explains Soft Gamma Repeaters. Even originally $(1970-80)$ most authors unified GRB/SGR models , since last fifteen years are commonly separated by their repeater and spectra differences and finally their much nearer galactic distances; however we and other have shown that they, rarely, openly shared the same spectra, time and flux structures. Last SGR1900+14 (May-August-October 1998) events and SGR1627-41 (June-October 1998) events did exhibit at peak intensities hard spectra comparable with classical GRBs. Indeed the SGR1900+14 event BATSE trigger 7171 left an almost identical event comparable to a just following GRB (trigger 7172) on the same day, same detector, with same spectra and comparable flux (Fargion 1998-1999) . This Hard-Soft connection has been re-discovered and confirmed more recently by BATSE group (Woods et all 1999) with an additional hard event of SGR 1900+14 recorded in GRB990110 event.
Additional GRB-SGR connection occur between GRB980706 event with an almost identical (in time, channel spectra, morphology and intensities) observed in GRB980618

originated by SGR 1627-41. Nature would be very perverse in mimic two signals, (even if at different distances and different powers), by two extreme different source engines. This points once again to their common Nature. At least SGRs offer the unique occasion for a study of a near-by laboratory GRB to a better understanding of both models. However they are both up present times usually described by catastrophic spherical explosions, Fireball and Magnetar Models. Their different distances, cosmic versus galactic ones, imply very different power source Jet, but their morphological similarity strongly suggest an unique process: the blazing of a spinning and multi-precessing gamma Jet, from either Neutron Star or Black Hole. The γ Jet is born by high GeVs electron pairs Jet which are regenerating, via Inverse Compton Scattering, an inner collimated beamed γ (MeVs) precessing Jet. The thin jet (an opening angle inverse of the electron Lorentz factor, a milli-radiant or below), while spinning, is driven by a companion and/or an asymmetric accreting disk in a Quasi Periodic Oscillation (QPO) and in a Keplerian multi-precessing blazing mode: its $\gamma - X$ ray lighthouse trembling and flashing is the source of the complex and wide structure of observed Gamma Bursts. These γ Jets share a peak power of a Supernova ($10^{44} ergs^{-1}$) at their birth (during SN and Neutron Star formations), decaying by power law $\sim t^{-1} - \sim t^{-(1.5)}$ to less power-full Jets that converge to present persistent SGRs stages. Indeed these ones are blazing events from late relic X pulsar observable only at nearer distances. The γ Jet emit in general at $\sim 10^{35}$ ergs^{-1} powers; both of GRB and SGR show an apparent luminosity amplified by the inverse square of the thin from 10^{-3} to 10^{-4} radiant angle Jet beaming: the corresponding solid angle Ω spreads between 10^{-7} and 10^{-9} leading to the necessary amplification for both SN-GRB and X pulsar-SGR . Optical-Radio After-Glows are not the fading fireball explosion tails often observed in puzzling variable non monotonic decay, but the averaged external Jet tails moving and precessing and geometrically fading away. The rare optical re-brightening (the so called SN bump) observed in few afterglow has been, very probably, erroneously associated to an underlying isotropic SN flash: the optical re-brightening afterglow is in general the late re-crossing of the precessing Jet tail periphery toward the observer direction. The averaged integral optical signal (within thousand of seconds) hide the short-scale oscillatory behaviour of the precessing Jet. In particular the geometrical beaming offered in the rare GRB970508 a peculiar optical re-brightening and a manifest late radio oscillating afterglow of the cycloidal lighthouse Jet.

2. The geometrical multi-precessing Gamma Jet and GRB bursting signature

We imagine the GRB and SGR nature as the early and the late stages of jets fueled first by SN event and later by a disk or a companion (WD, NS) star. Their binary angular velocity ω_b reflects the beam evolution $\theta_1(t) = \sqrt{\theta_{1m}^2 + (\omega_b t)^2}$ or more generally a multi-precessing angle $\theta_1(t)$ (Fargion & Salis 1996):

$$\theta_1(t) = \sqrt{\theta_x^2 + \theta_y^2} \tag{1}$$

$$\theta_x(t) = \theta_b sin(\omega_b t + \varphi_b) + \theta_{psr} sin(\omega_{psr} t) + \theta_N sin(\omega_N t + \varphi_N) \tag{2}$$

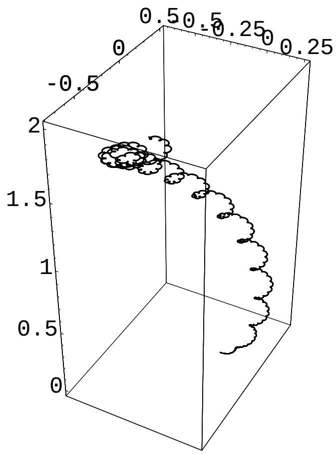

Fig. 1. Leth:Three dimensional space evolution of the Precessing Gamma Jet leading, by its blazing to X precursor and main GRBs. Right: the same pattern observed from above along the vertical axis , in the orthogonal two dimensional plane

$$\theta_y(t) = \theta_{1m} + \theta_b cos(\omega_b t + \varphi_b) + \theta_{psr} cos(\omega_{psr} t) + \theta_N cos(\omega_N t + \varphi_N) \qquad (3)$$

where θ_{1m} is the minimal angle impact parameter of the jet toward the observer, θ_b, θ_{psr}, θ_N are, in the order, the maximal opening precessing angles due to the binary, spinning pulsar, nutation mode of the jet axis. For a 3D pattern and its projection along the vertical axis in an orthogonal 2D plane (Fig.1) The angular velocities combined in the multi-precession keep memory of the pulsar jet spin (ω_{psr}), the precession by the binary ω_b and an additional nutation due to inertial momentum anisotropies or beam-accretion disk torques (ω_N). On average, from eq.(5) the γ flux and the X optical afterglow decays, in first approximation, as t^{-2}; the complicated spinning and precessing jet blazing is responsible for the wide morphology of GRBs and SGRs as well as their internal periodicity.(See Fig.2). The consequent γ time evolution and spectra derived in this ideal models may be compared successfully with similar observed GRB data evolution as shown in Fig. 3, regarding X-ray precursors in $GRB971210, GRB971212, GRB990518, GRB000131$.
Similar descriptions with more parameters and with a rapid time evolution of the jet has been more recently also proposed by (Portegies Zwart et all 1999).

3. X Ray precursor as the fingerprint of Precessing Gamma Jets and the end of Fireballs

To choose for a model let us just consider with no prejudice the last reported (and most distant $z = 4.5$) event: GRB000131 and its X ray precursor:(fig 3,last). This event while being red-shifted and slowed down by a factor 5.5 exhibit on the contrary a short scale

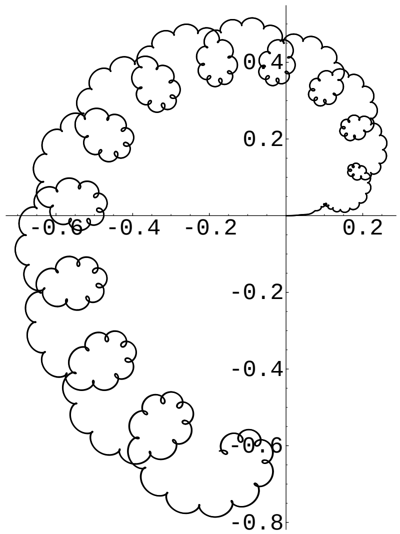

Fig. 2. Leth:Three dimensional space evolution of the Precessing Gamma Jet leading, by its blazing to X precursor and main GRBs. Right: the same pattern observed from above along the vertical axis , in the orthogonal two dimensional plane

time fine structure not explicable by any fireball model , but well compatible with a thin, fast spinning precessing γ jet. The extreme γ energy budget, calling for a comparable ν one, exceeds few solar masses in its main emission even for ideal full energy conversion. Moreover one must notice the presence of a weak X-ray precursor pulse lasting 7 sec, 62 sec before the huge main structured γ burst trigger. Its arrival direction (within 12 degree error) with main GRB is consistent only with the main pulse (a probability to occur by chance below 3.610^{-3}). The time clustering proximity (one minute over a day GRB rate average) has the probability to occur by chance below once over a thousand. The over all probability to observe this precursor by change is below 3.4 over a million making inseparable its association with the main GRB000131 event. This weak burst signal correspond to a power above a million Supernova and have left no trace or Optical/X transient just a minute before the real (peak power $>$ *billion* Supernova) energetic event. Similar X precursors occurred in a non negligible minor sample of GRBs (see for example Fig 2-4a) and also few SGRs event (Fig 4b). No isotropic GRB explosive progenitor could survive such a disruptive isotropic(million supernova output) precursor trigger nor any multi-exploding jet. Only a persistent precessing Gamma Jet crossing nearby the observer direction twice could naturally explain it.

4. Thin Precessing γ Jet and the GRB-SN Connection

Statistical arguments (Fargion 1998, 1999) favor a unified GRBs model based on blazing, spinning and precessing thin jet. We assume that GRB jet arise in most SNe outbursts. The far GRBs are observables at their peak intensities (coincident to SN) while blazing

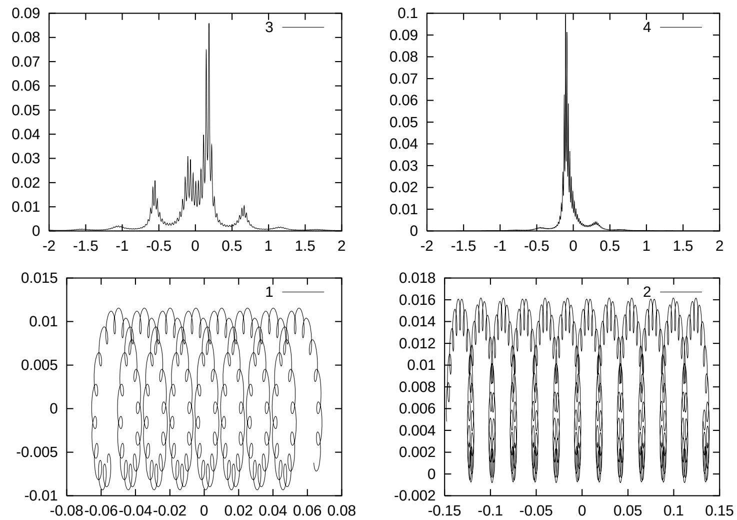

Fig. 3. Down : Label 1 and 2, in two different bi-dimensional angle Spinning, Precessing Gamma Jet ring patterns toward the detector at the origin $(0, 0)$ corresponding to previous like 3D precessing jet. Up: Label 3-4, the consequent X, γ intensity time evolution signals derived by ICS formula. X ray precursor may naturally arise in some configurations.

in axis to us within the thin jet very rarely; consequently the hit of the target occurs only within a wide sample of sources found in a huge cosmic volume. In this frame work the GRB rate do not differ much from the SN rate. Assuming a SN-GRB event every 30 years in a galaxy and assuming a thin angular cone ($\Omega <$(1/4)10^{-8}) the probability to be within the cone jet in a ($4 * 10^{10}$)cosmic sample of galaxies (at limited Hubble R$\geq$ 28 magnitude) within our main present observable Universe volume ($z \sim$ 1-$z \sim$ 4) during one day of observation at a nominal 10 sec GRB duration is quite small: ($P < 10^{-2}$). This value should be suppressed by nearly an order of magnitude because of the detector acceptance. However a precessing gamma jet whose decaying scale time is a thousand time longer than the GRB itself (decaying by a power law $\sim t^{-1}$) whose scale time is nearly ten or twenty thousand of seconds, may fit naturally the observed GRB rate. Moreover the jet pressure could also accumulate gas and form dense filaments. Such filaments fragment as well as gravitationally cluster leading to contemporaneous stellar arc formations.(Y.Efremov&D.Fargion, 2000). This phenomena might explain why GRBs seem to be associated with star formation regions.

5. GRBs Energy Budget in Fireball and the Neutrino ν and γ ejection

Gamma Ray Bursts as recent GRB990123 and GRB990510 emit, for isotropic explosions, γ energies as large as two solar masses annihilation. These energies are underestimated because of the neglected role of comparable ejected MeV (Comptel signal) neutrinos ν bursts and assume an unrealistic ideal energy conversion efficiency. Indeed,

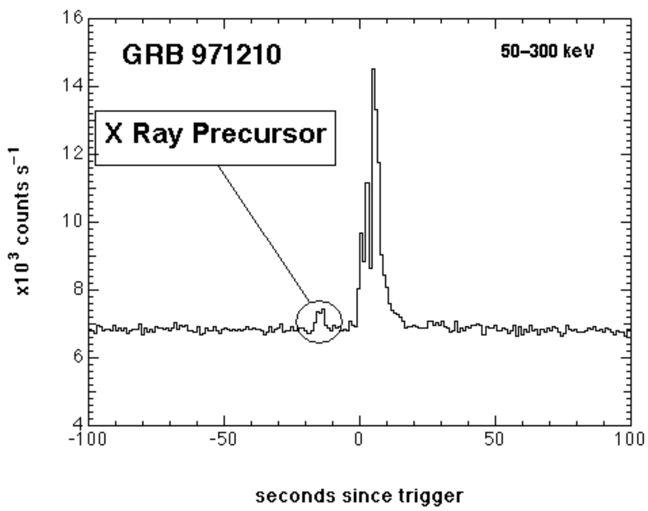

Fig. 4. Up: Time evolution and X precursors in GRB 971210

as often neglected, it is important to remind that the huge energy bath (for a fireball model) on GRB990123 imply also a corresponding neutrino burst. As in hot universe, if entropy conservation holds, the ν energy density factor to be added to the photon γ budget is at least ($\simeq (21/8) \times (4/11)^{4/3}$). If entropy conservation do not hold the energy needed is at least a factor [21/8] larger than the gamma one. The consequent total energy-mass needed for the two cases are respectively 3.5 and 7.2 solar masses. Additional factors must be introduced for realistic energy conversion efficiency leading to energies as large as tens of solar masses. No fireball by NS may coexist with it. Jet could. These extreme power cannot be explained with any standard spherically symmetric Black Hole Fireball model. A too heavy Black Hole (hundred or thousands solar masses) or, worse, Star would be unable to coexist with the shortest millisecond time structure of Gamma Ray Burst. Cosmological and nearby Gravitational Red-shifts may only make the Fireball Model more inconsistent. Smaller size BH or NS do not offer enough mass reserve. Beaming of the gamma radiation may overcome the energy puzzle along with the short scale-time. However any mild "explosive beam" event as some models (Wang & Wheeler 1998) ($\Omega > 10^{-2}$) would not solve the jet containment at the corresponding disruptive energies. Moreover such a small beaming would not solve the huge GRBs flux energy windows ($10^{47} \div 10^{54}$ erg/sec), keeping GRB980425 and GRB990123 within the same GRB framework. Only extreme beaming ($\Omega \sim 10^{-8}$), by a slow decaying, but long-lived precessing jet, may coexist with characteristic Supernova energies, apparent GRBs output and the puzzling GRB980425 statistics as well as the GRB connection with older, nearer and weaker SGRs relics. Therefore SGRs are very useful nearby astrophysical Laboratory where to study and test the far GRB process. SGRs are not associated with huge OT afterglow or explosive SN event : they have lost

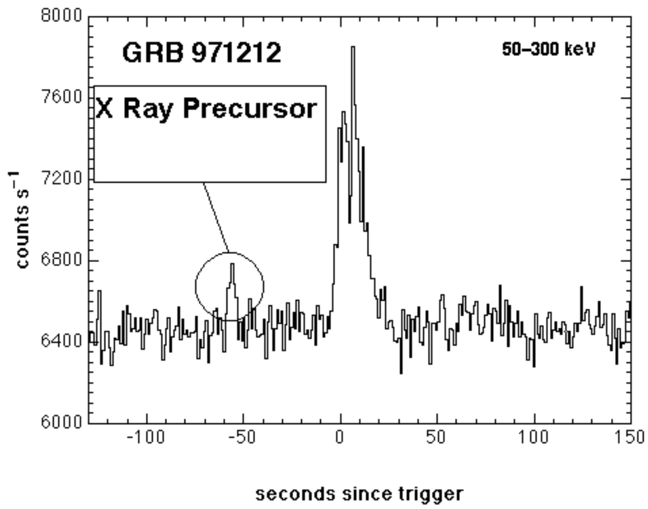

Fig. 5. Up: Time evolution and X precursors in GRB 971212.

their primordial SNR shells elsewhere while escaping at high velocity far from the SN birth place.

6. Hard Gamma Jet by Inverse Compton Scattering by GeV Electron Pairs beam

A jet angle related by a relativistic kinematics would imply $\theta \sim \frac{1}{\gamma_e}$, where γ_e is found to reach $\gamma_e \simeq 10^3 \div 10^4$ (Fargion 1994, 1998). At first approximation the gamma constrains is given by Inverse Compton relation: $< \epsilon_\gamma > \simeq \gamma_e^2\, kT$ for $kT \simeq 10^{-3} - 10^{-1}\, eV$ and $E_e \sim GeVs$ leading to characteristic X-γ GRB spectra. The origin of $GeVs$ electron pairs are very probably decayed secondary related to primary inner muon pairs jets, able to cross dense stellar target. The consequent adimensional photon number rate (Fargion & Salis 1996) as a function of the observational angle θ_1 responsible for peak luminosity becomes

$$\frac{\left(\frac{dN_1}{dt_1\, d\theta_1}\right)_{\theta_1(t)}}{\left(\frac{dN_1}{dt_1\, d\theta_1}\right)_{\theta_1=0}} \simeq \frac{1 + \gamma^4\, \theta_1^4(t)}{[1 + \gamma^2\, \theta_1^2(t)]^4}\, \theta_1 \approx \frac{1}{(\theta_1)^3} \quad . \tag{4}$$

The total fluence at minimal impact angle θ_{1m} responsible for the average luminosity is

$$\frac{dN_1}{dt_1}(\theta_{1m}) \simeq \int_{\theta_{1m}}^{\infty} \frac{1 + \gamma^4\, \theta_1^4}{[1 + \gamma^2\, \theta_1^2]^4}\, \theta_1\, d\theta_1 \simeq \frac{1}{(\,\theta_{1m})^2} \quad . \tag{5}$$

These spectra fit GRBs observed ones (Fargion & Salis 1995). Assuming a beam jet intensity I_1 comparable with maximal SN luminosity, $I_1 \simeq 10^{45}\ erg\, s^{-1}$, and replacing this value in the above a-dimensional equation we find a maximal apparent GRB power

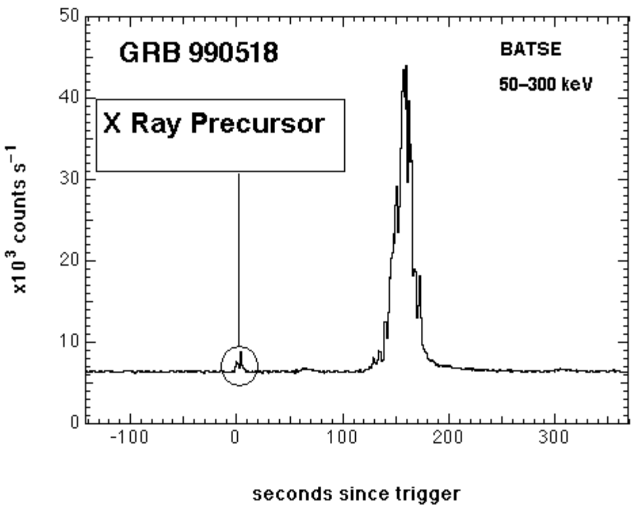

Fig. 6. Time evolution and X precursors in GRB 990518.

for beaming angles $10^{-3} \div 3 \times 10^{-5}$, $P \simeq 4\pi I_1 \theta^{-2} \simeq 10^{52} \div 10^{55} erg\, s^{-1}$, just within observed ones. We also assumed a power law jet time decay as follows

$$I_{jet} = I_1 \left(\frac{t}{t_0}\right)^{-\alpha} \simeq 10^{45} \left(\frac{t}{3 \cdot 10^4 s}\right)^{-1} \; erg\, s^{-1} \tag{6}$$

where ($\alpha \simeq 1$) is a value able to reach, at 1000 years time scales, the present known galactic micro-jet (as SS433) intensities powers: $I_{jet} \simeq 10^{39}\; erg\, s^{-1}$. This offer a natural link between the GRB and the SGR out-put powers. We used the model to evaluate if April precessing jet might hit us once again. It should be noted that a steady angular velocity would imply an intensity variability ($I \sim \theta^{-2} \sim t^{-2}$) corresponding to some of the earliest afterglow decay law.

7. Precessing Jet Relics in action

The Gamma Jet progenitor of the GRB is leaving a trace in the space: usually a nebulae where the nearby ISM may record the jet sweeping as a three dimensional screen. The outcomes maybe either a twin ring as recent SN1987A has shown, or helix traces as the Cat Eye Nebula or more structured shapes as plerions and hourglass nebulae. We imagine the jet as born by a binary system (or by an asymmetric disk accreting interaction) where the compact companion (BH or NS) is the source of the ultra relativistic electron pair jet (at tens GeV. Inverse Compton Scattering on IR thermal photons will produce a collinear gamma jet at MeV). The rarest case where the jet is spinning and nearly isolated would produce a jet train whose trace are star chains as the Herbig Haro ones (Fargion, Salis 1995). When the jet is modified by the magnetic field torque of the

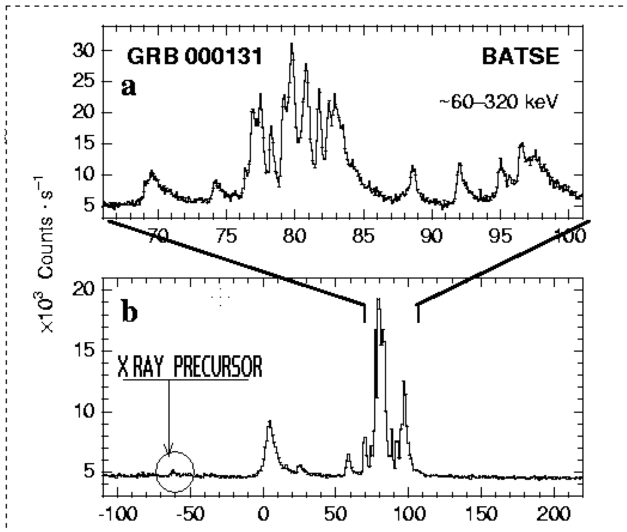

Fig. 7. Time evolution and X precursors in most distant (red-shift 4.5) GRB 000131.

binary companion field the result may be a more rich cone shape. If the ecliptic lay on the same plane orthogonal to the jet in an ideal circular orbit than the bending will produce an ideal twin precessing cones which is reflected in an ideal twin rings (Fargion, Salis 1995). If the companion is in eccentric orbit the resultant conical jet will be more deflected at perihelion while remain nearly undeflected at a aphelion. The consequent off-axis cones will play the role of a mild ”rowing” acceleration able to move the system and speed it far from its original birth (explosive) place. Possible traces are the asymmetric external twin rings painted onto the spherical relic shell by SN1987a. Fast relics NS may be speeded by this processes (Fargion, Salis 1995a, 1995b, 1995c). Because of momentum conservation this asymmetric rowing is the source of a motion of the jet relic in the South-East direction. In extreme eccentric system the internal region of the ring are more powered by the nearby encounter leading to the apparent gas arcs. If the system is orbiting in a plane different from the one orthogonal to the jet the outcoming precessing jet may spread into a mobile twin cone whose filling may appear as a full cone or a twin hourglass by a common plerion shape. At late times there is also possible apparent spherical shapes sprayed and structured by a chaotic helix. External ISM distribution may also play a role enhancing some sides or regions of the arcs. The same presence of external relic shells may explain the possible new evidences of iron lines observed by Beppo-Sax satellite. We may explain these rare signal as the re-illuminated isotropic emission due to the under-line beamed inner light-house γ Jet. The integral jet spray in long times may mimic even spherical envelopes but internal detailed inspection might soon reveal the thinner jet origin (as in recent Eta Carina string jets). Variable nebulae behaviours recently observed are confirming our present scenario.

8. Conclusions

Gamma Ray Burst call for extreme isotropic power or extreme collimation or both. Fore a decade the isotropic Fireball story hold the market. Now a Fireball-Jet compromise start to float on the community. Like a ghost.
We strongly believe that GRBs and SGRs are persistent blazing flashes from light-house thin γ Jet spinning in multi-precessing (binary, precession, nutation) mode. These Jets are originated by NSs or BH in binary system or disk powered by infall matter: the Jet is not a single explosive event even in GRB, but they are powered at maximal output during SN event.The Jet power is comparable to SN at its peak; the γ Jet has a chain of progenitor identities: it is born in most SN and or BH birth and it is very probably originated by very collimated primary muon pairs at GeVs-TeVs energies. These muons could cross the dense target matter around the SN explosions, nearly transparent to photon-photon opacities. These muon progenitors might be themselves secondary relics of pion decays or even by a more transparent beamed ultra-high energy neutrino Jet originated (by hadronic and pion showering) near the NS or BH. The high energy relativistic muons decay in flight in electron pairs is itself source of GeVs relativistic pairs whose Inverse Compton Scattering with nearby thermal photon is the final source of the observed hard X - γ Jet. The relativistic morphology of the Jet and its multi-precession is the source of the puzzling complex X-γ spectra signature of GRBs and SGRs. Its inner internal Jet contain, following the relativistic Inverse Compton Scattering, hardest and rarest beamed GeVs-MeVs photons (as the rarest and long life EGRET GRB940217 one) but its external Jet cones are dressed by softer and softer photons. This onion like multi Jets is not totally axis symmetric: it doesn't appear in inner structure, on its front, as a concentric ring serial; while turning and spraying around it is deformed (often) into an elliptical off-axis concentric rings preceded by the internal harder center leading to a common hard to soft GRBs (and SGRs) train signal. In our present model and simulation this internal effect has been here neglected without any major consequence. The complex variability of GRBs and SGRs are simulated successfully by the equations and the consequent geometrical beamed Jet blazing leading also to the observed rare $X-\gamma$ signatures. As shown in fig 2 the slightly different precessing configurations could easily mimic the wide morphology of GRBs as well as the surprising rare X-ray precursor shown in Fig. 3 above.

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